Sources of reionization and galaxy evolution under the microscope

Prezentuje: Uroš Meštrić

- Work-experience/interests -

Galaxy evolution and formation:

- High-redshift galaxies
- Sources of reionization
- Galaxy physical and morphological properties
- Galaxy scaling relations
- Sources in lensed fields
- Emission line galaxies
- **Time-delay cosmography, Strong lensing modeling, Transients**

Observations:

- Spectroscopy,
- Photometry

reduction – analysis –interpretation

- HST, ESO VLT, Keck, CFHT, JWST

Tools:

- Python (.....)
- IRAF
- Galfit
- Sourc-Extractor
- A-Phot
- TOPCAT
- qFitsView
- pandora easy-z
- DS9, GAIA
- ...

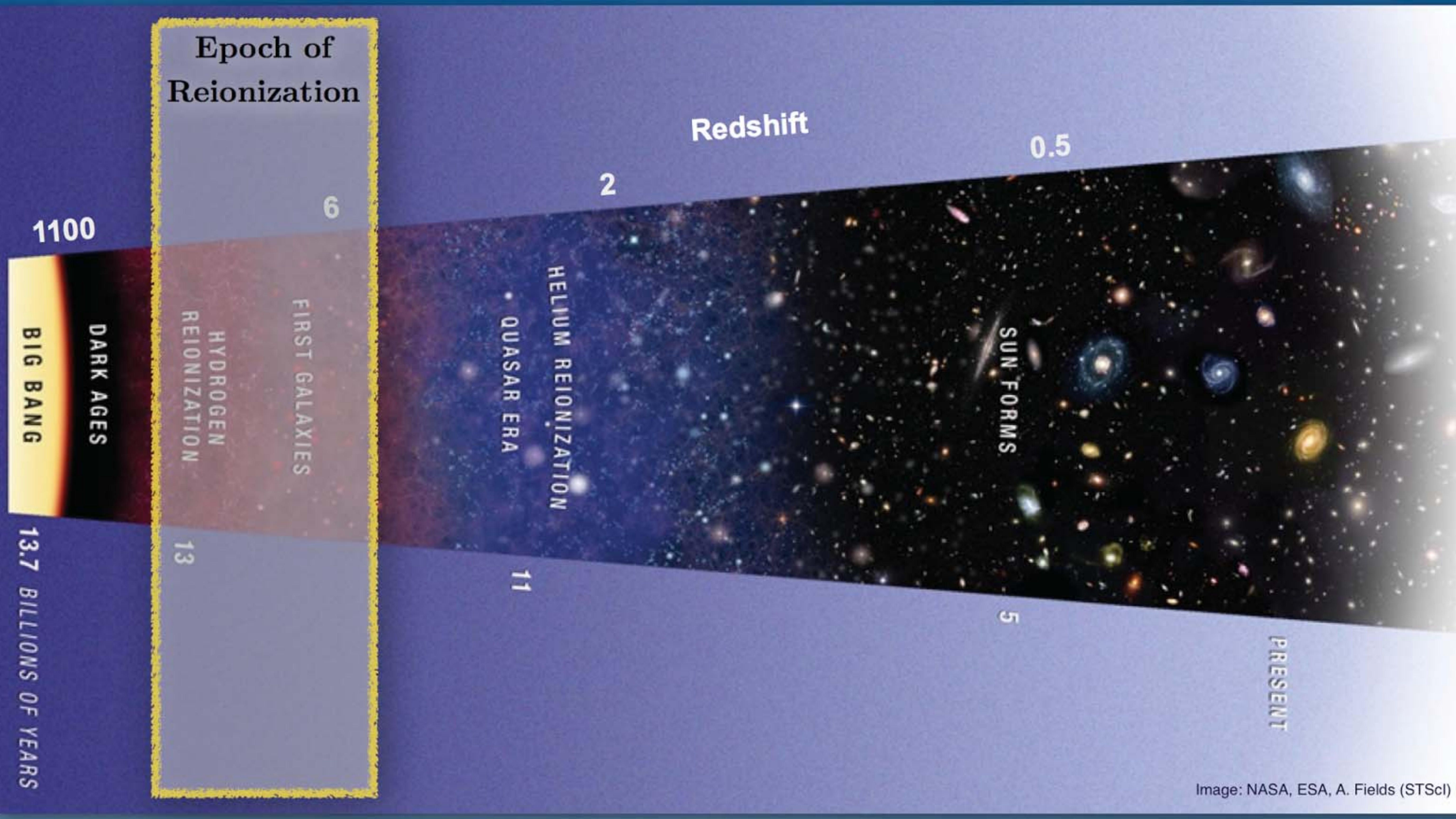
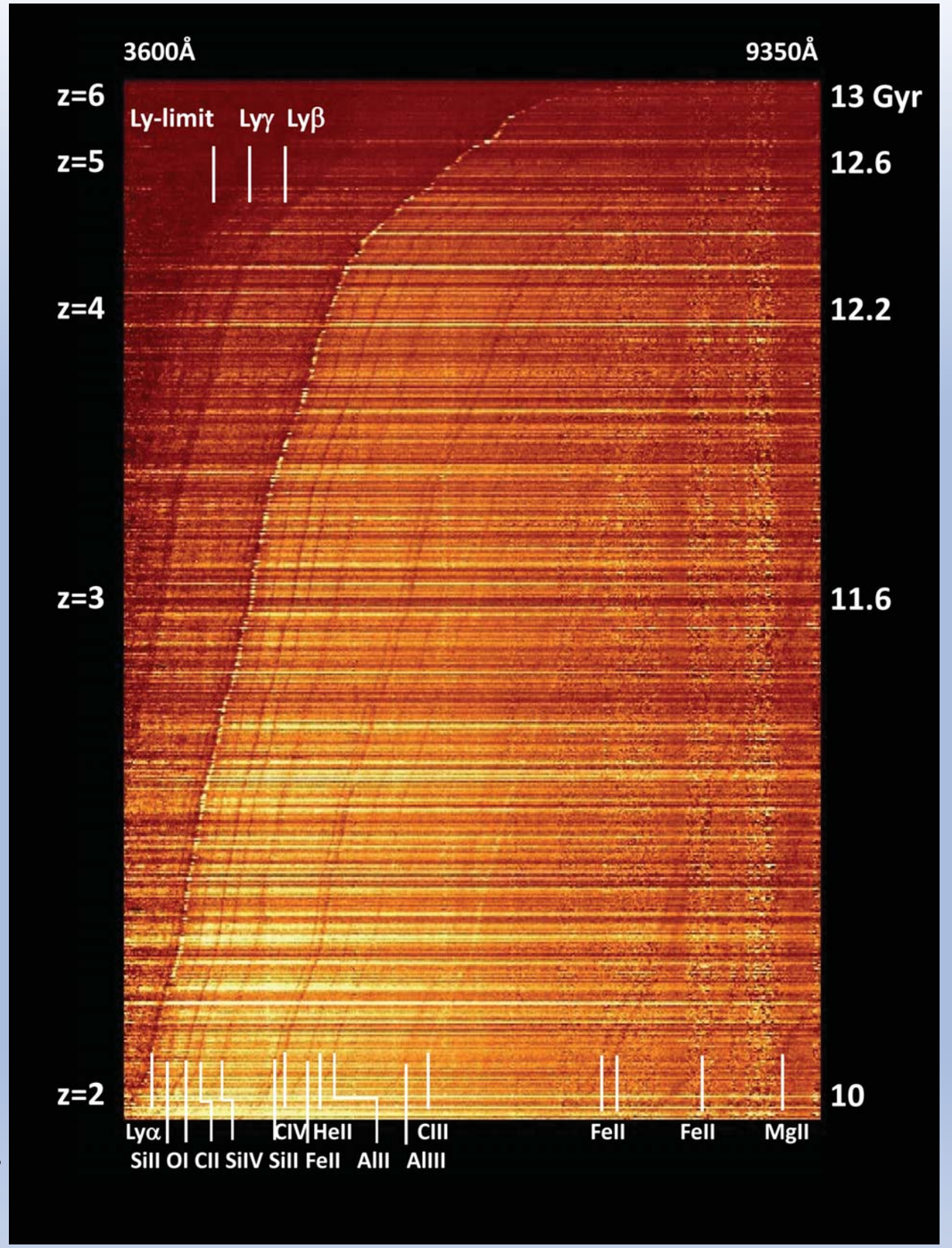


Image: NASA, ESA, A. Fields (STScI)

Research work:

Reionization:

- Galaxies as main drivers of reionization?
  Galaxies, are they alone sufficient to reionize the Universe?
- Observable signatures of Lyman continuum leakers?
  Color, morphology, Ly-alpha properties …
- *Detecting and measuring Lyman continuum (LyC) escape fraction.*
- Development of the efficient selection criteria for LyC leakers.



VIMOS Ultra Deep Survey (Le Fevre et al. 2015)

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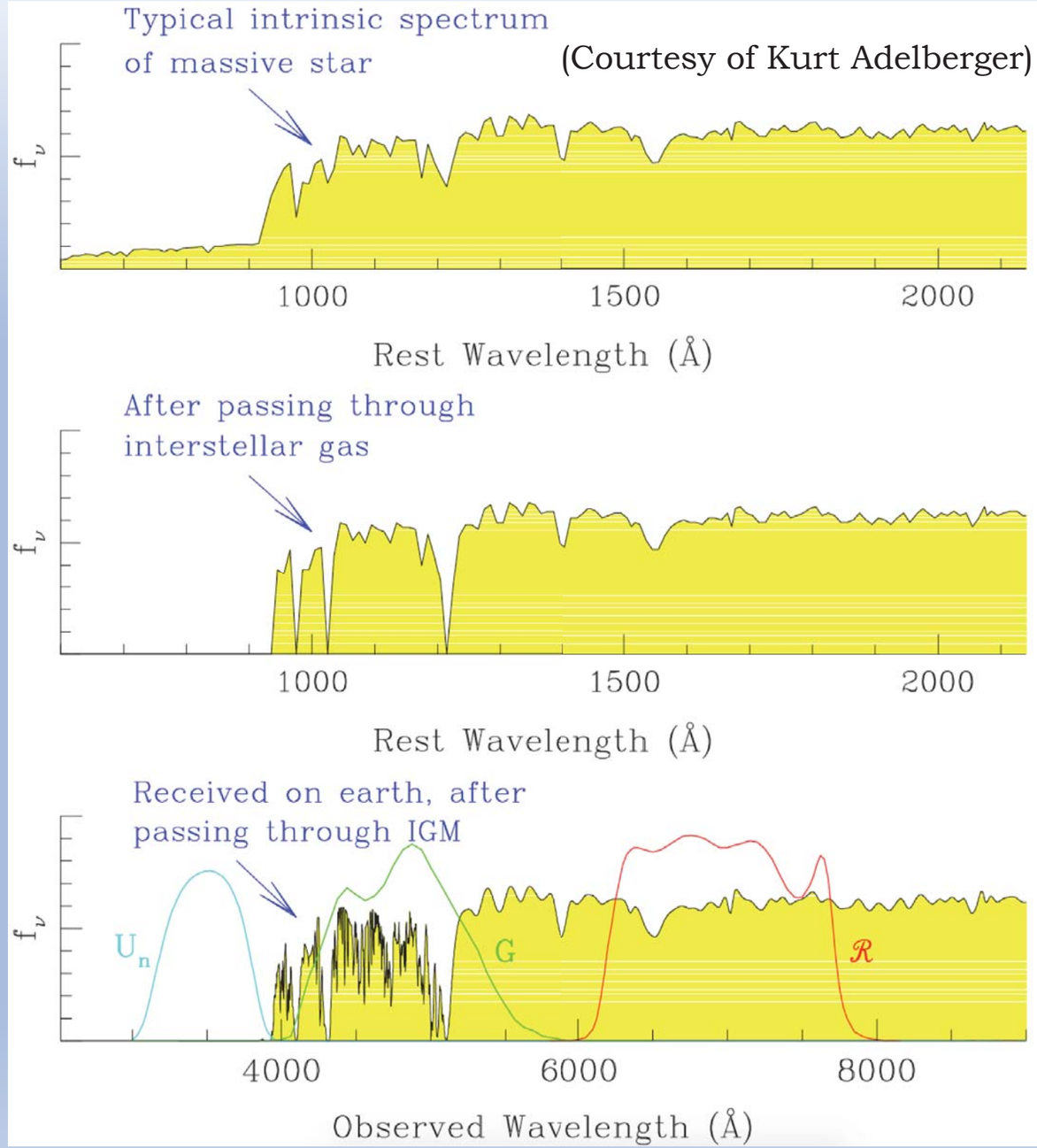

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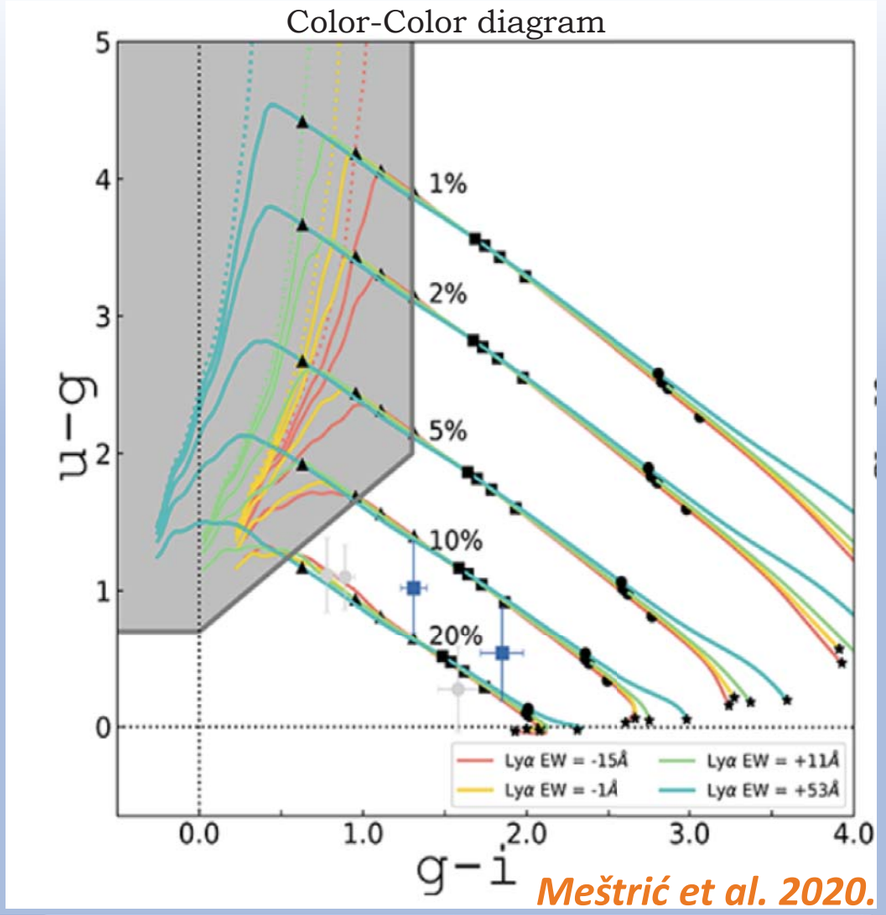
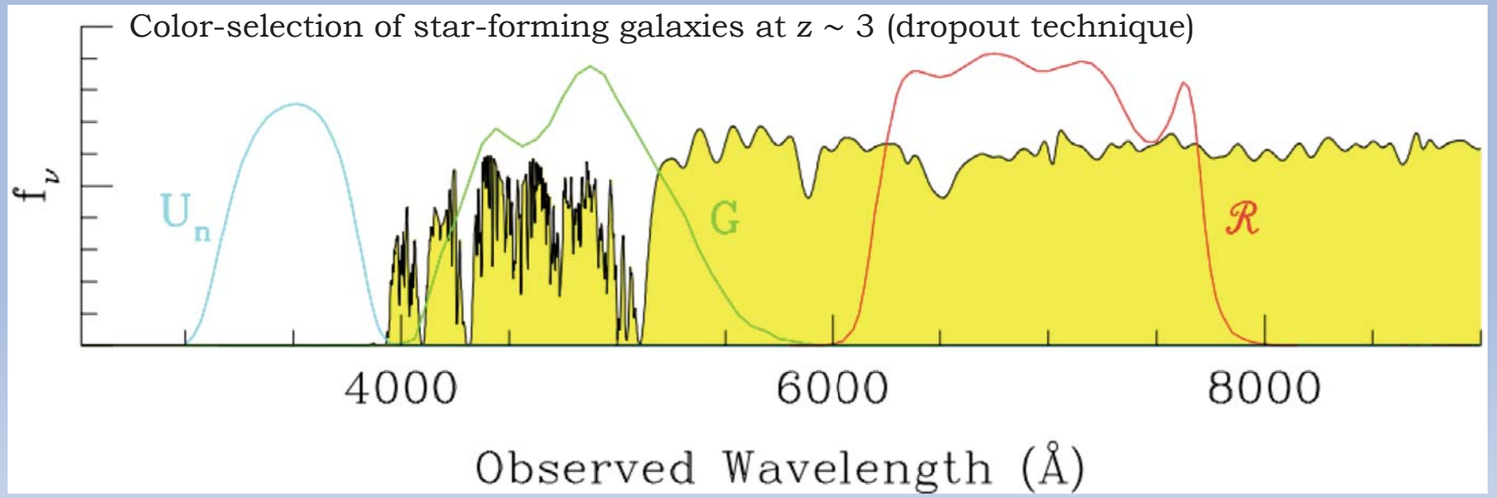
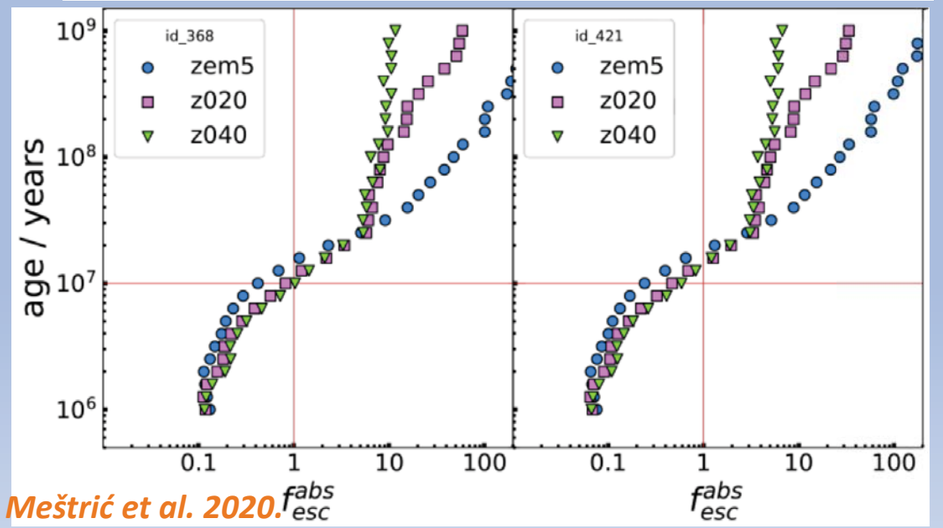


Meštrić et al. 2020.





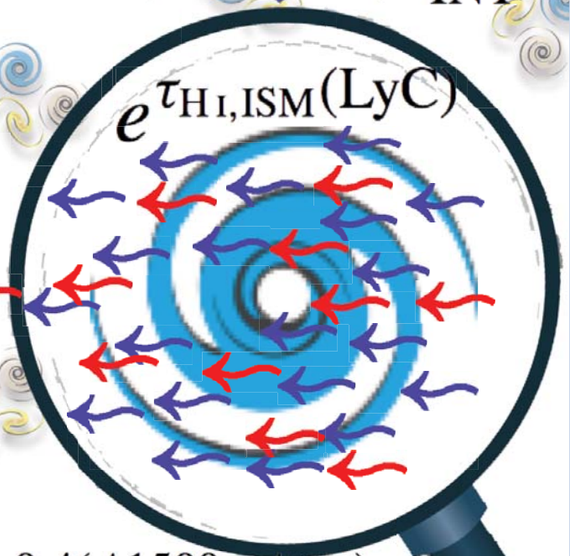
Meštrić et al. 2020.

Definition of the escape fraction

$$\left(\frac{F1500}{F_{\mathrm{LyC}}}\right)_{\mathrm{OBS}}$$

$$\left(\frac{L1500}{L_{\mathrm{LyC}}}\right)_{\mathrm{INT}}$$

$$e^{\tau_{\mathrm{H\,I,IGM}}(\mathrm{LyC})}$$



$$e^{\tau_{\mathrm{H\,I,ISM}}(\mathrm{LyC})}$$

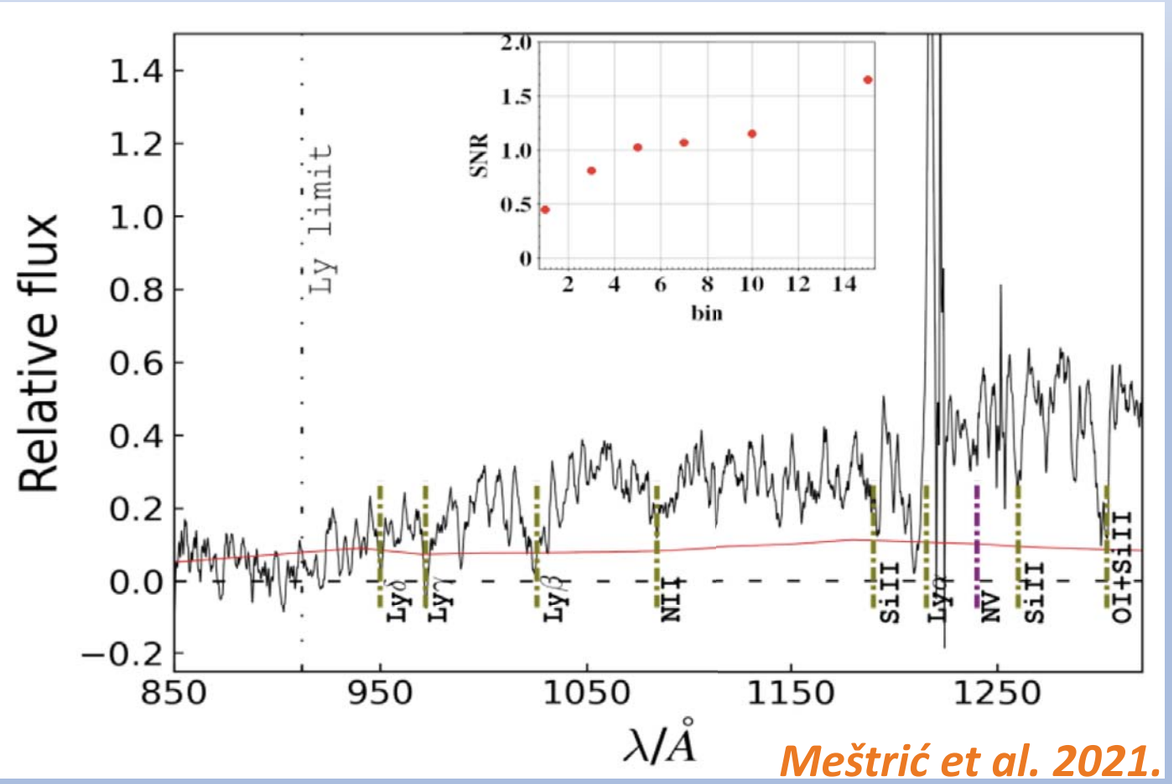
$$10^{-0.4(A1500-A_{\mathrm{LyC}})}$$

$$f_{\mathrm{esc,rel}} = \frac{(L1500/L_{\mathrm{LyC}})_{\mathrm{int}}}{(F1500/F_{\mathrm{LyC}})_{\mathrm{obs}}} \exp\left(\tau_{\mathrm{LyC}}^{\mathrm{IGM}}\right)$$

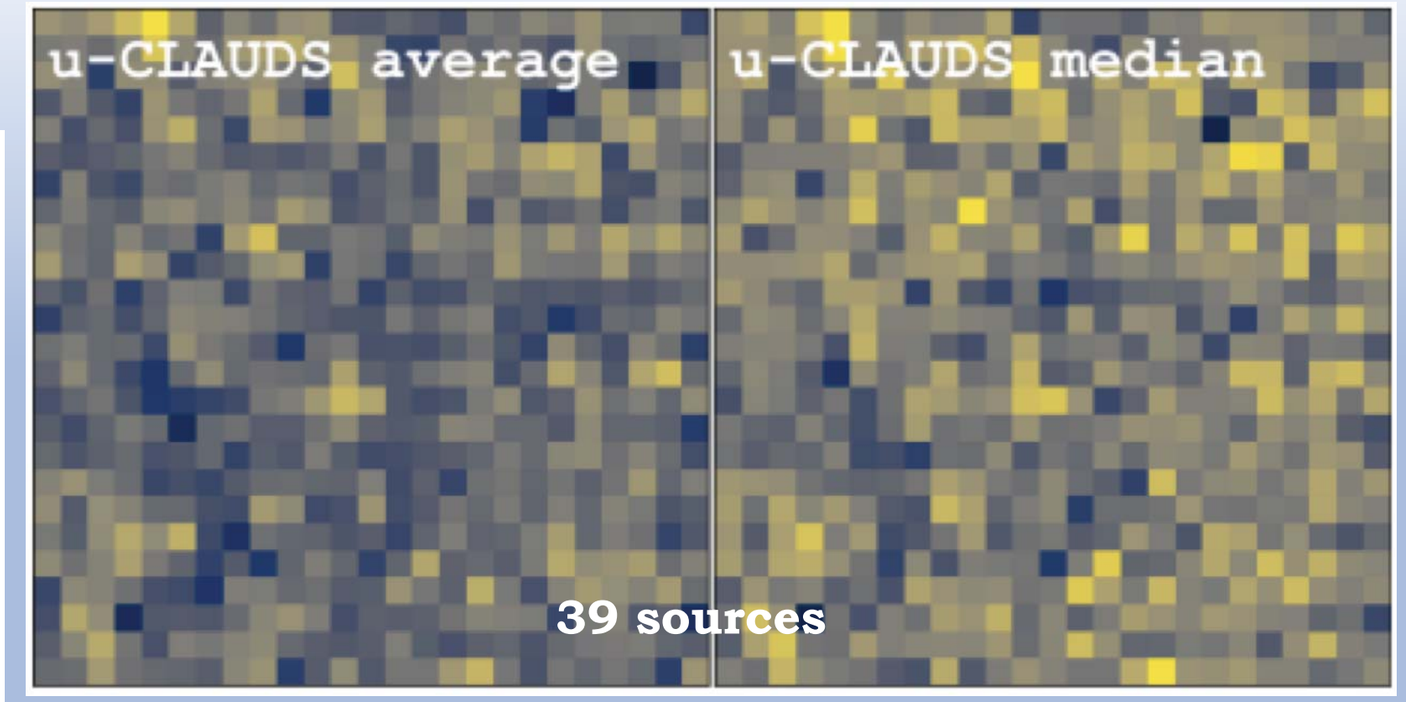
$$f_{\mathrm{esc}} = 10^{-0.4A_{1500}} f_{\mathrm{esc,rel}}$$

Research work:

Reionization:



Meštrić et al. 2021.



Meštrić et al. 2020.

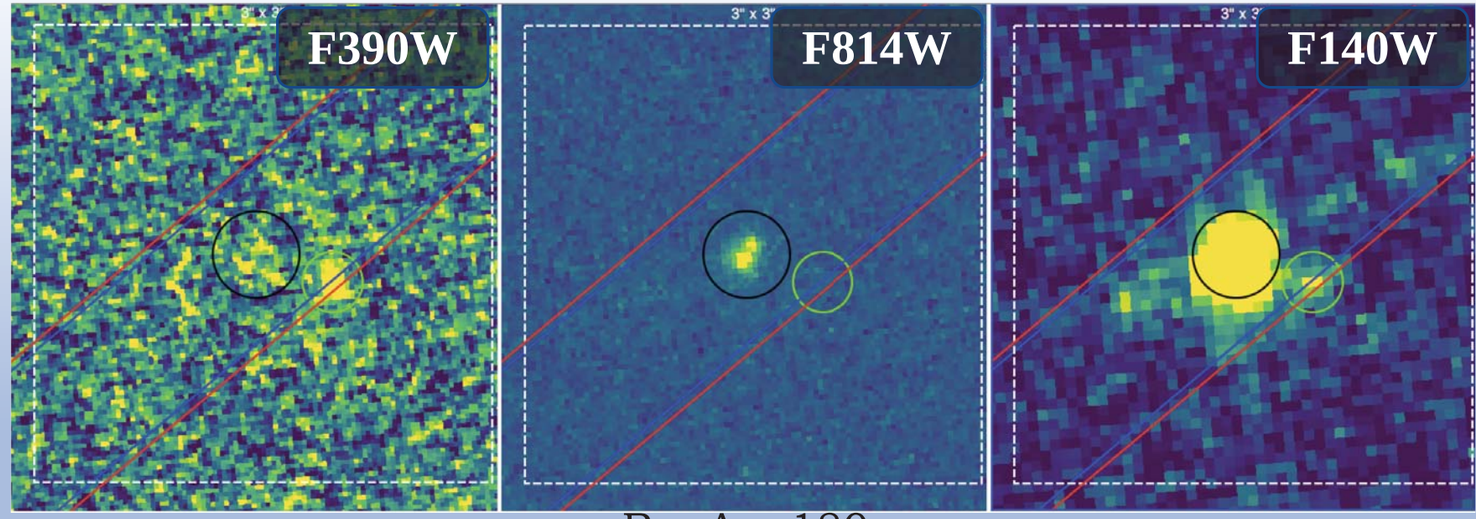
Reionization with non-LyC detections

- **"Non LyC leakers" large amount of unexplored ancillary data → HST F275W, F336W, F390W and MUSE/VLT ...**

Research work:

Reionization - Ion3

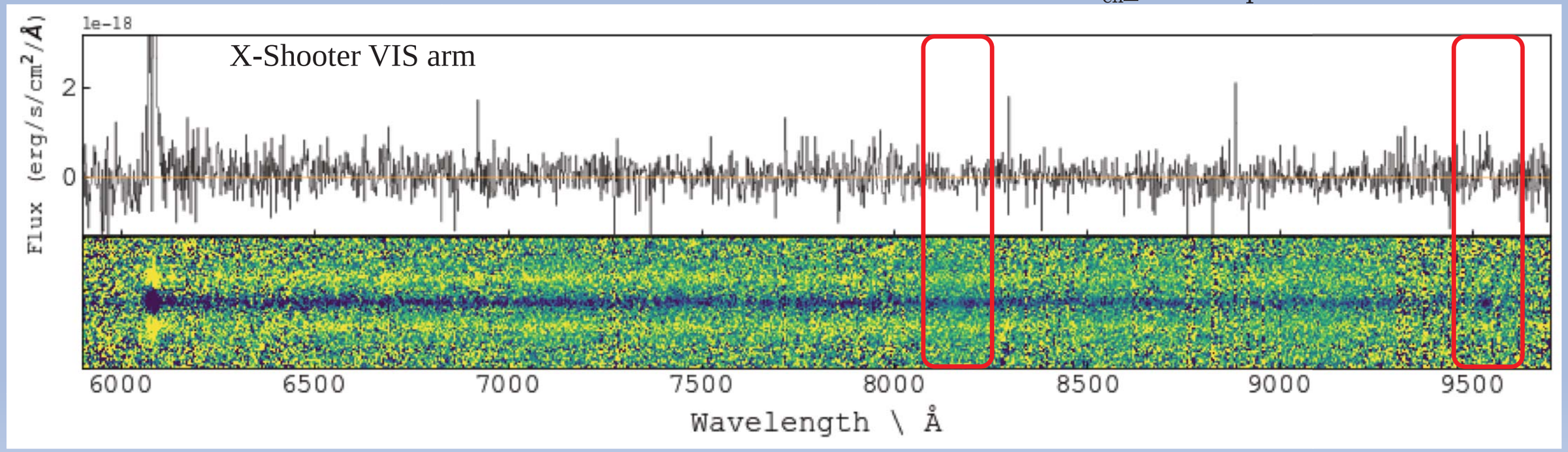
- photometric, spectroscopic and morphological analysis (**HST multi-band imaging PI: Meštrić**)



f_{esc} ~ 0.09 – 0.16

R_{eff}_A ~ 180pc

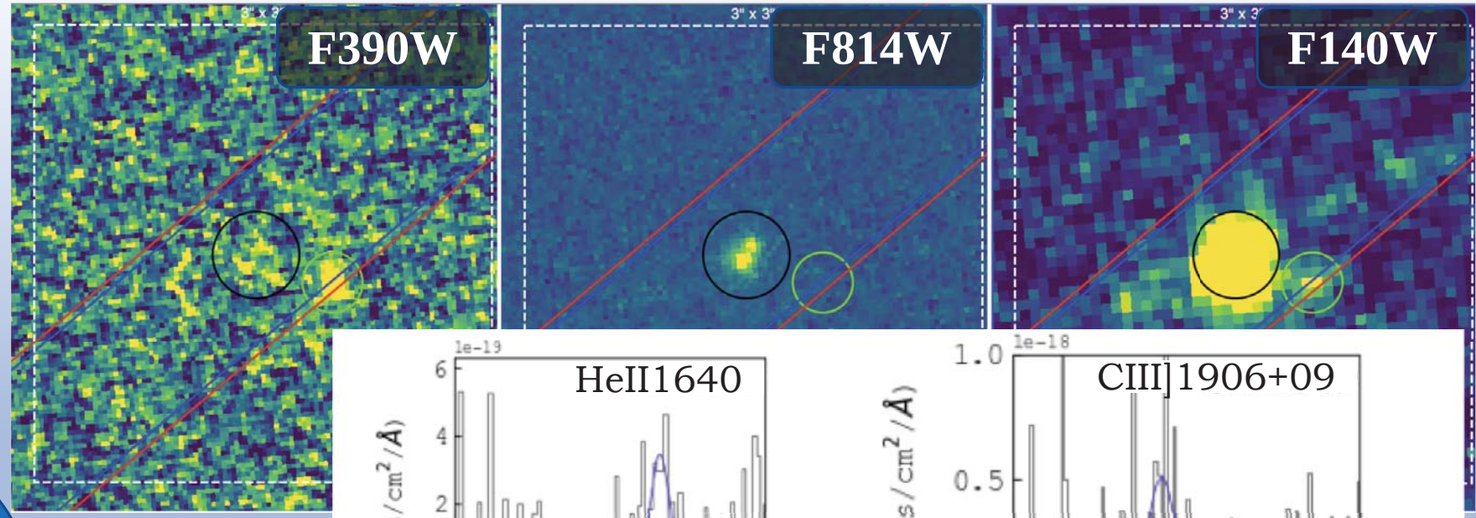
R_{eff}_B < 100pc



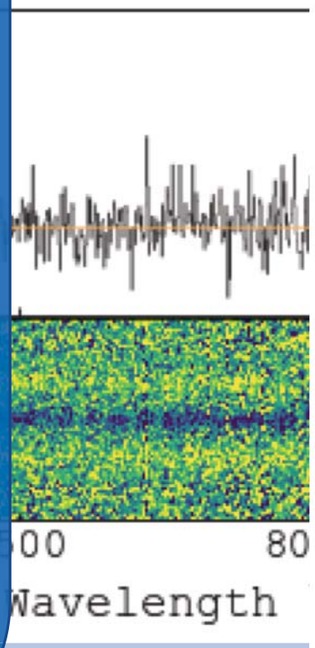
Research work:

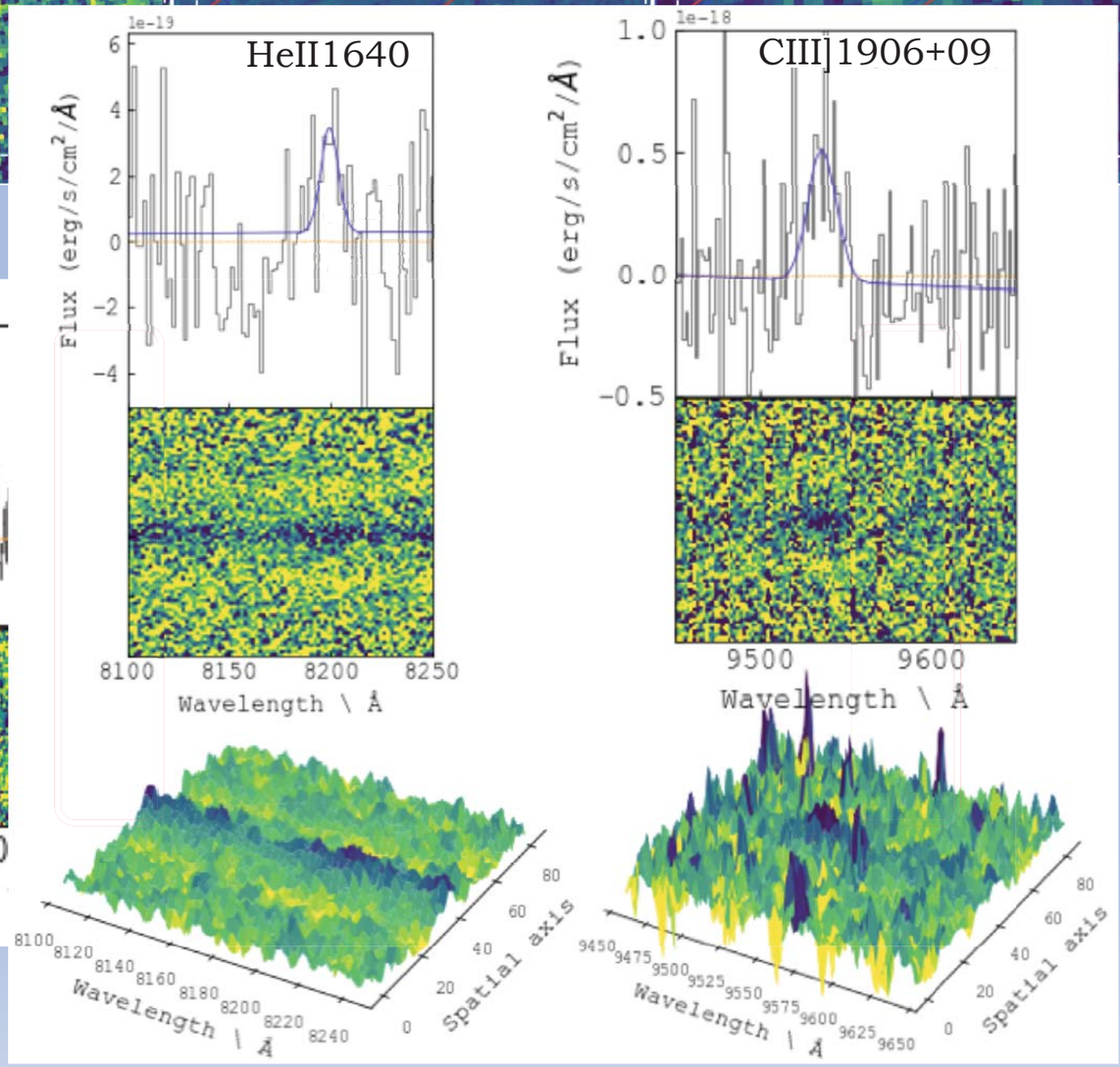
Reionization - Ion3

- photometric, spectroscopic and morphological analysis (**HST multi-band imaging PI: Meštrić**)



f_{esc} ~ 0.09 –

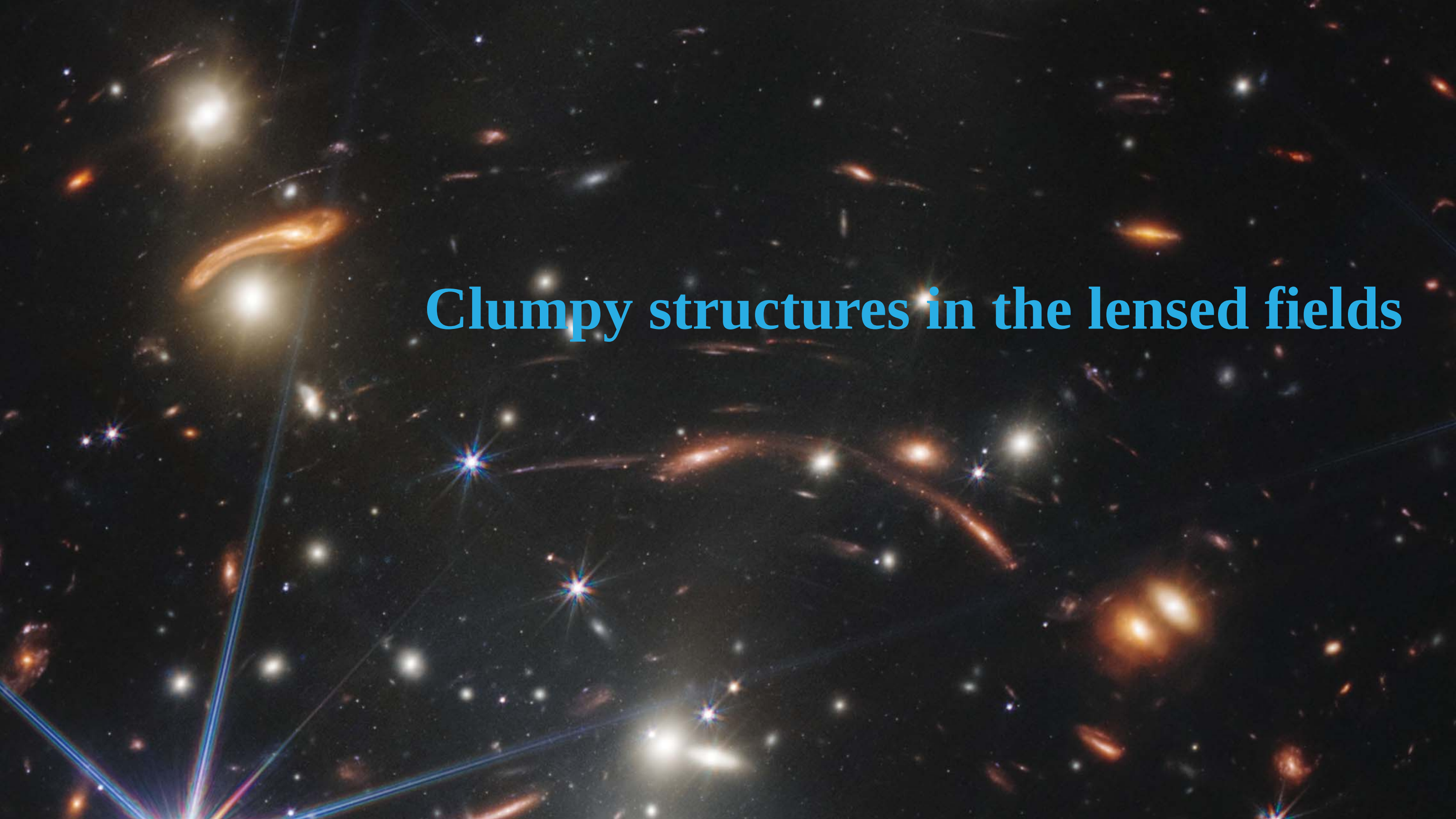




Ion3 properties:

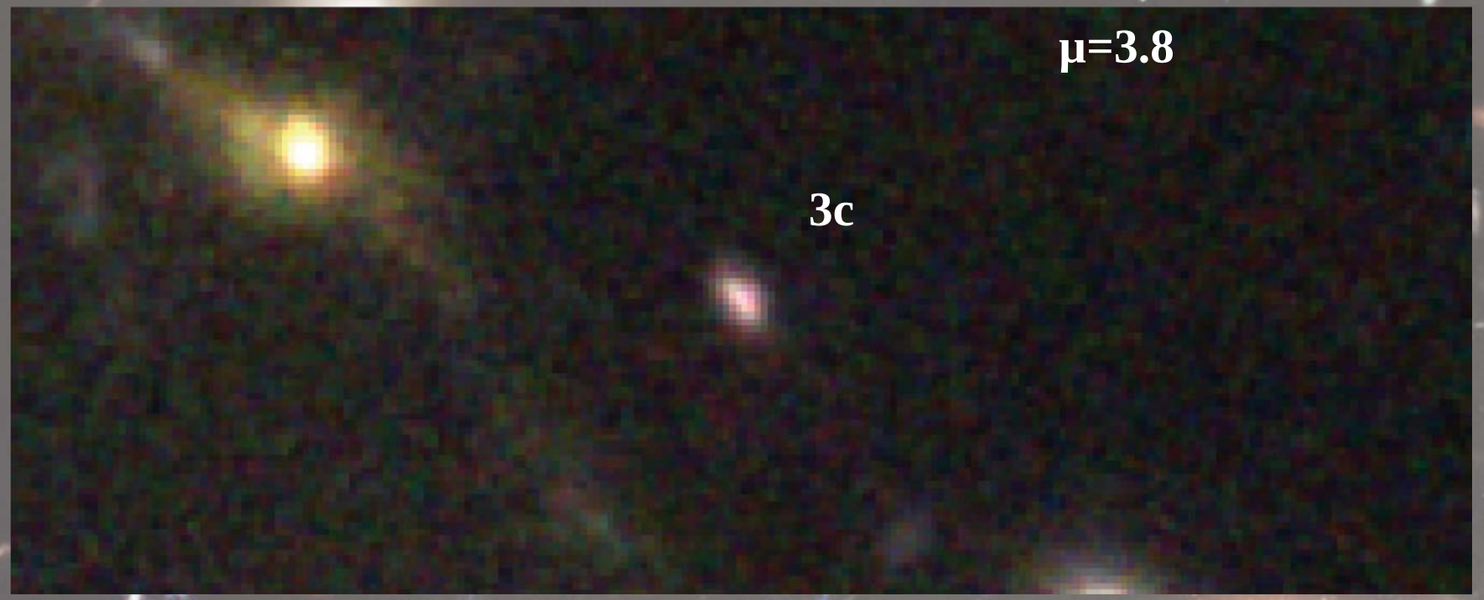
- $n_e^{[OII]}$=2300 ± 1900 cm^{-3}, $n_e^{CIII]} > 10^4$ cm^{-3}
- $SFR_{H\alpha}$≈100 ± 30 $M_\odot$ yr^{-1}, $SFR_{[OII]}$ ≈15 $M_\odot$ yr^{-1}
- 12+log(O/H) = 8.0 ± 0.2 … ($EW_{CIII]}$)
- [OIII]/[OII] ≈ 100 (using empirical and theoretical correlations)

Implies the existence of intense starbursts and the presence of massive and young stars.


Clumpy structures in the lensed fields

clumps in SMACS 0723 investigated by Claeyssens+2022

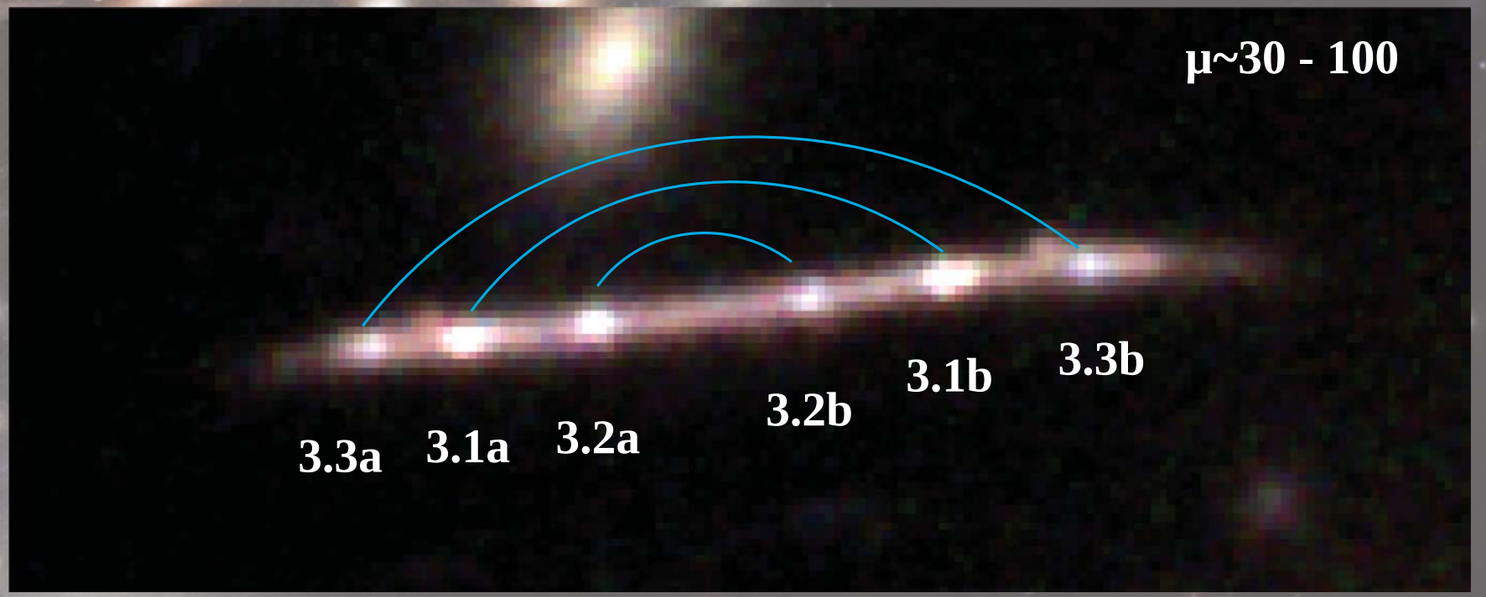
Why lensed fields?



- field A2744

- System 3 at *z~4* presented in Vanzella+2022

- JWST F115W + F150W + F200W



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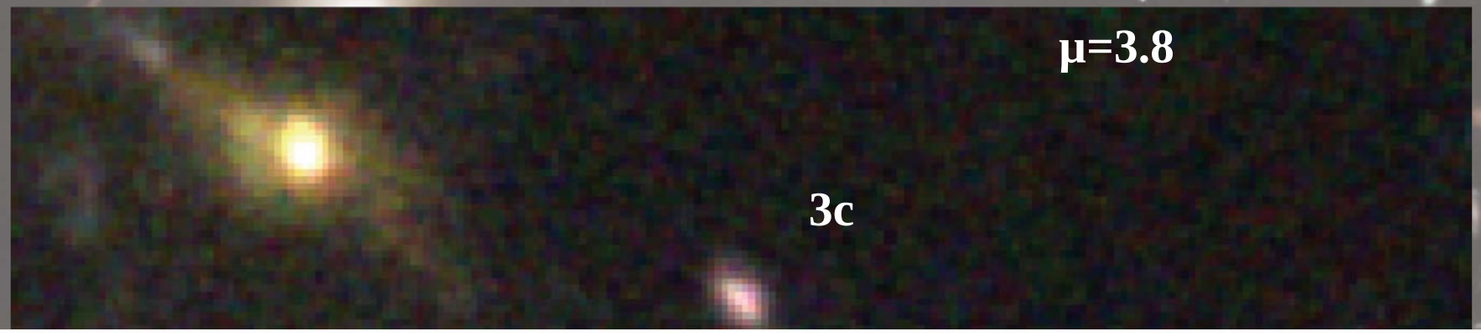

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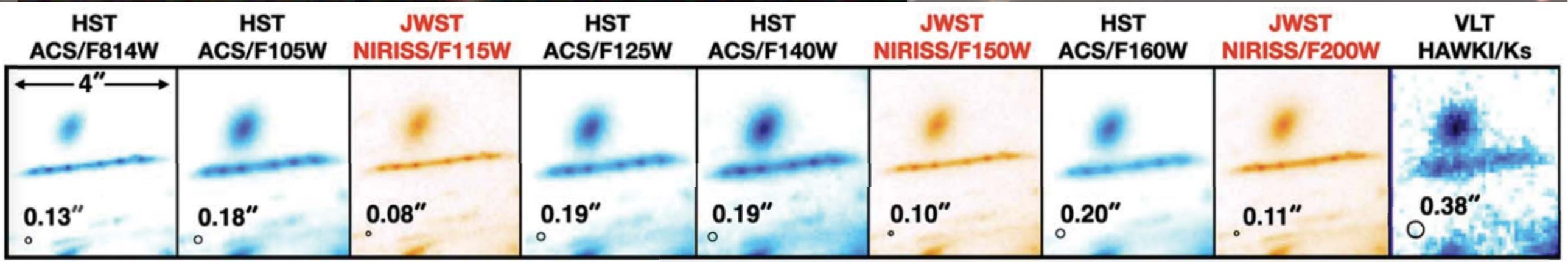
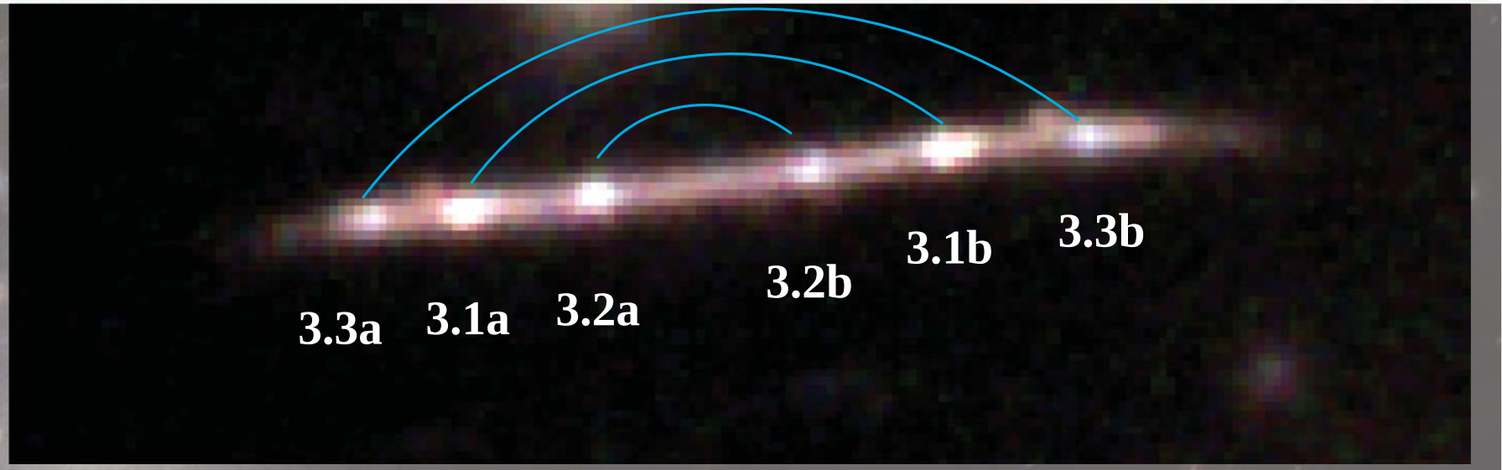




Clumps (compact stellar systems?)

Field galaxies

- Morphology of high-z objects dominated by **“giant-clumps”**

*(e.g. **Cowie+1995, Elmegreen+2005, Shibuya+2016, Guo+2018, Zanella+2019**)*

- Stellar masses $M_\star \sim 10^9 M_\odot$

*(e.g. **Förster Schreiber+2011, Guo+2012, Elmegreen+2013**)*

- Sizes: ~1kpc

*(e.g. **Guo+2011, Förster Schreiber+2011**)*

Lensed galaxies

- Morphology of high-z objects dominated by **“clumpy structures”**

*(e.g. **Cowie+1995, Elmegreen+2005, Shibuya+2016, Guo+2018, Zanella+2019**)*

- Stellar masses: $M_\star < 10^8 M_\odot$!

*(e.g. **Vanzella+2022, Meštrić+2022**)*

- Sizes: ~ 500pc - 3pc

*(e.g. **Livermore+2012, Vanzella+2017, Cava+2018, Bouwens+2022, Vanzella+2022, Meštrić+2022, Welch+2022**)*

Clumps – *Q/A* –

(Open questions ...)

- How galaxies grow in mass with cosmic time?
- Role of the clumps in process of galaxy evolution?
- Fate and life span of the clumps?
- Properties of the host …. ?
- How ionizing radiation can escape from clumps?
- … ?

Clumps - *methodology* -

- The **MUSE** Deep Lensed Field spectroscopy

(Vanzella+2021)

- **Precise lens model** ~180 multiple images, further on improved **~235** multiple images.

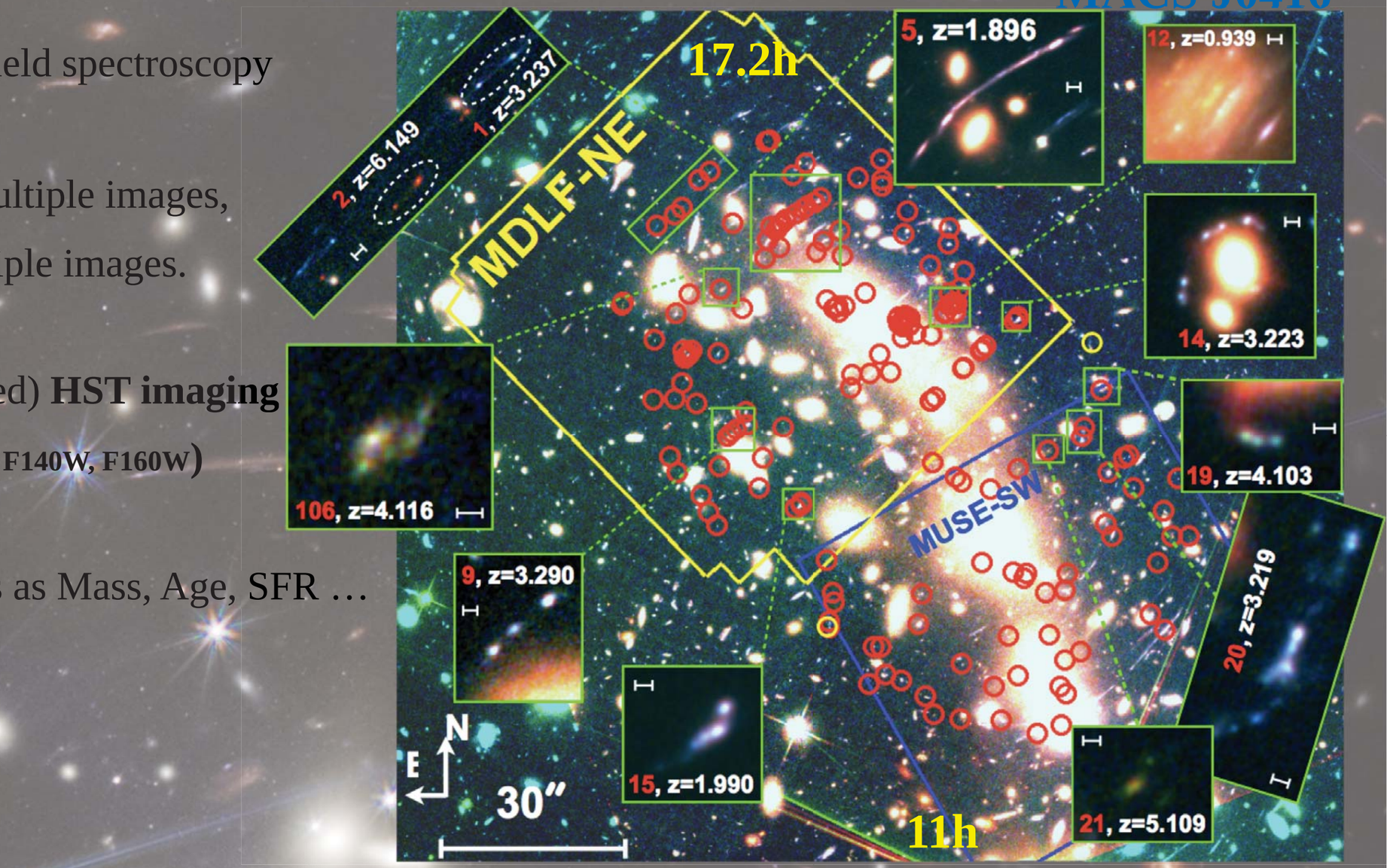
(Bergamini+2021)

- The multi band (PSF matched) **HST imaging** (**F435W, F606W, F814W, F105W, F125W, F140W, F160W**)

(Merlin+2016)

- SED modeling → properties as Mass, Age, SFR …

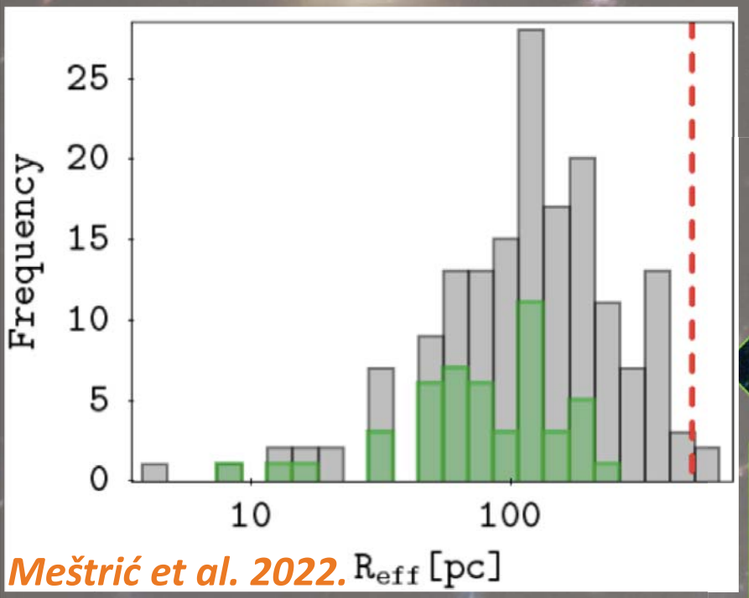
(Castellano+2016)

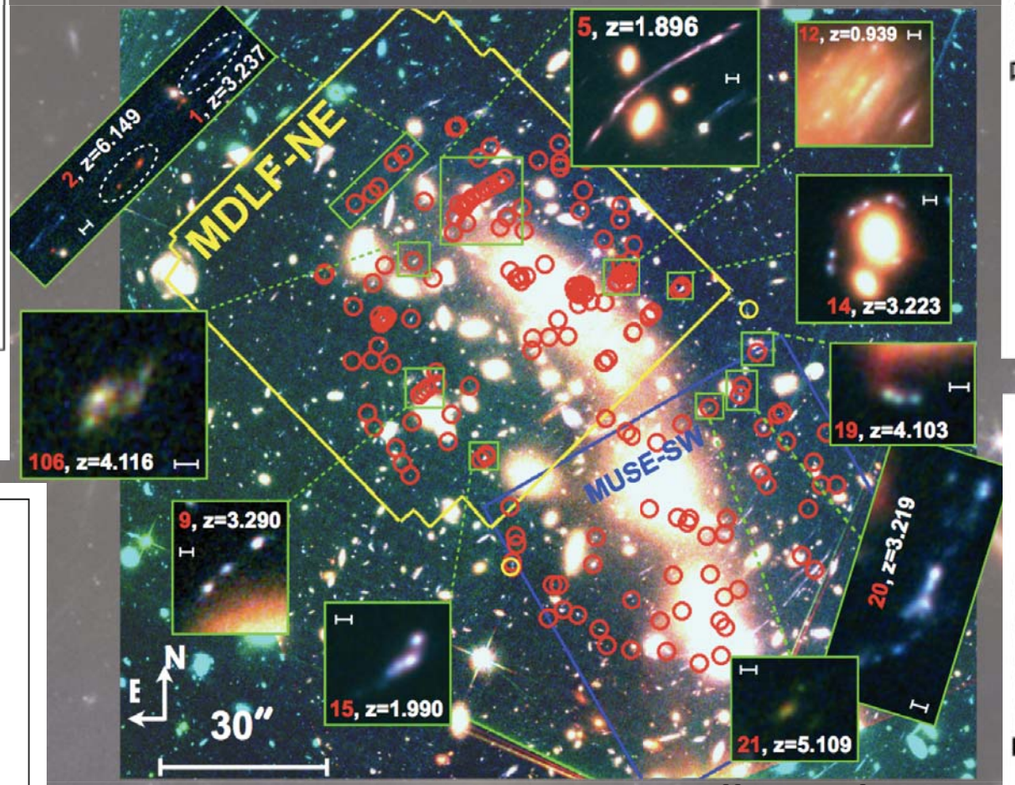


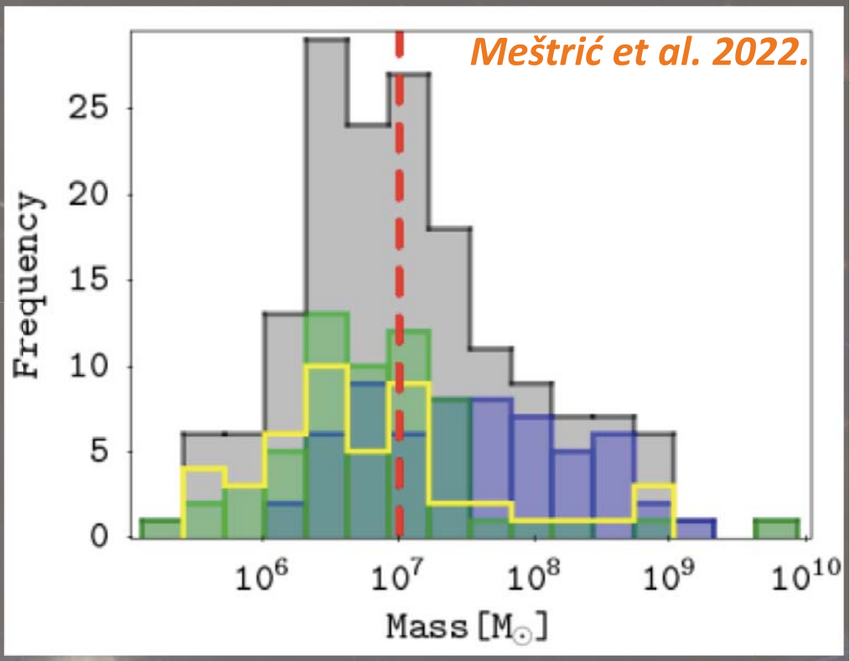
Vanzella+2021

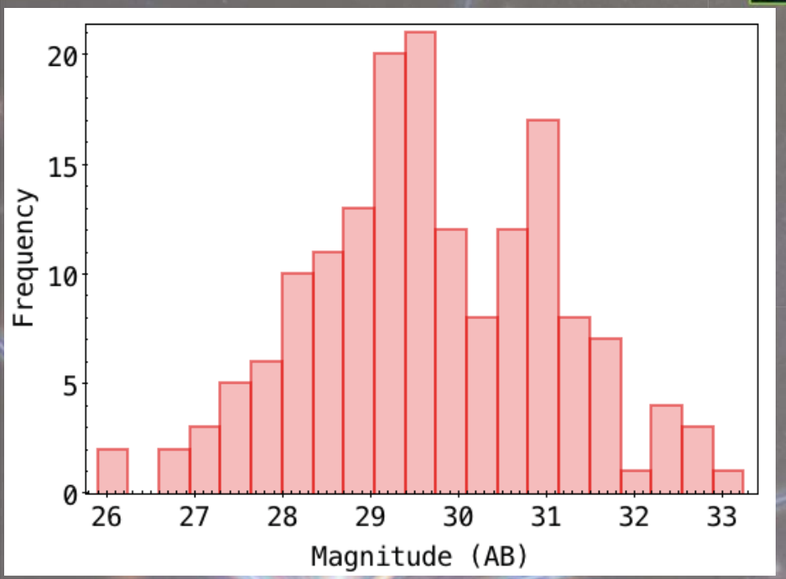
Galaxies and clumpy structures in lensed fields

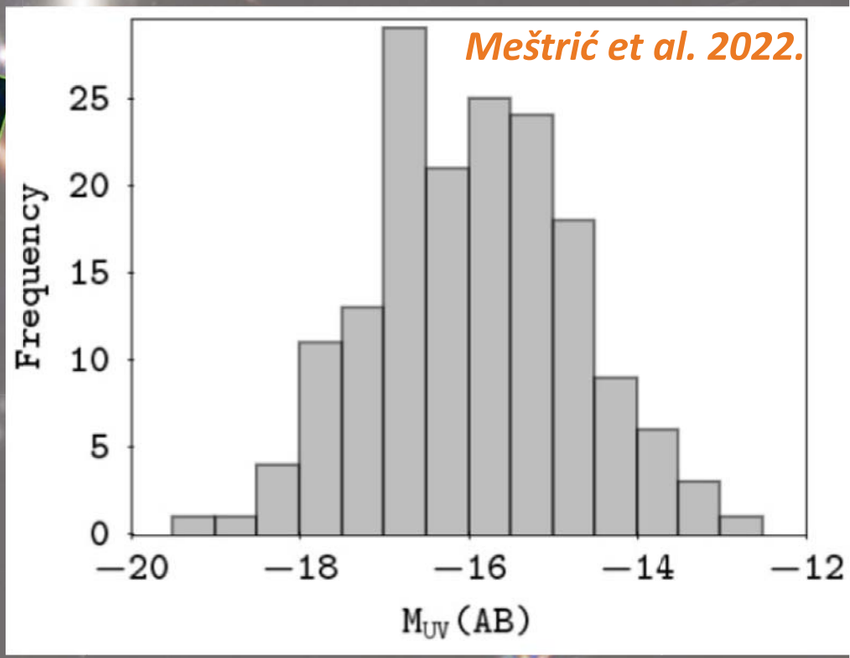
J0416











Clumps - *samples* -

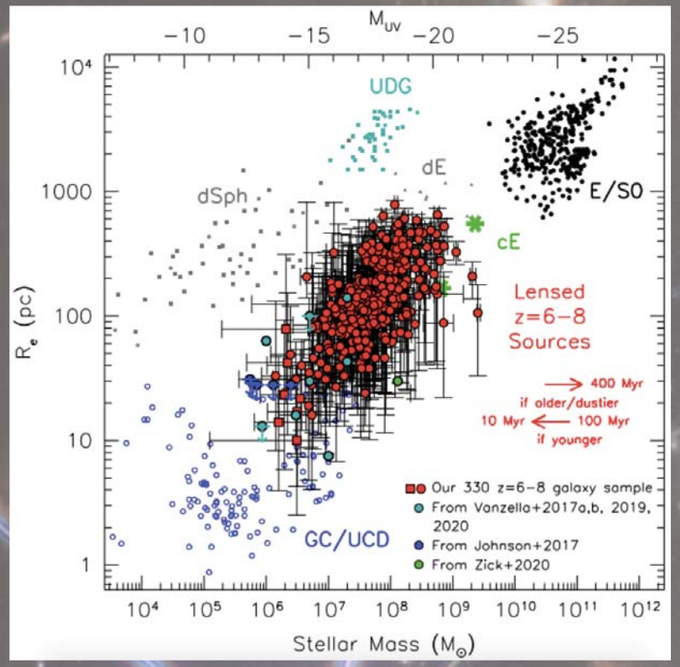
Bouwens+2021

- 333 sources

- z ~ 6 - 8 (photometry)

- various lens models

- ???



Clumps - *samples* -

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- 333 sources
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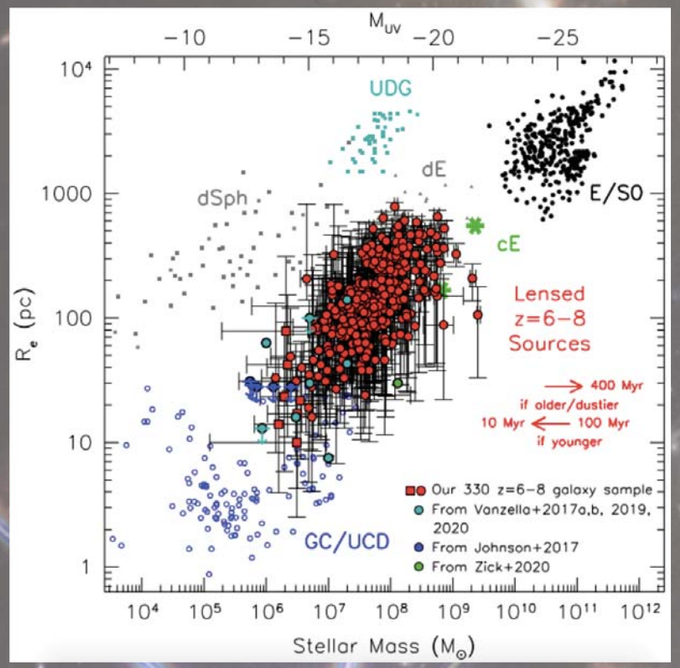
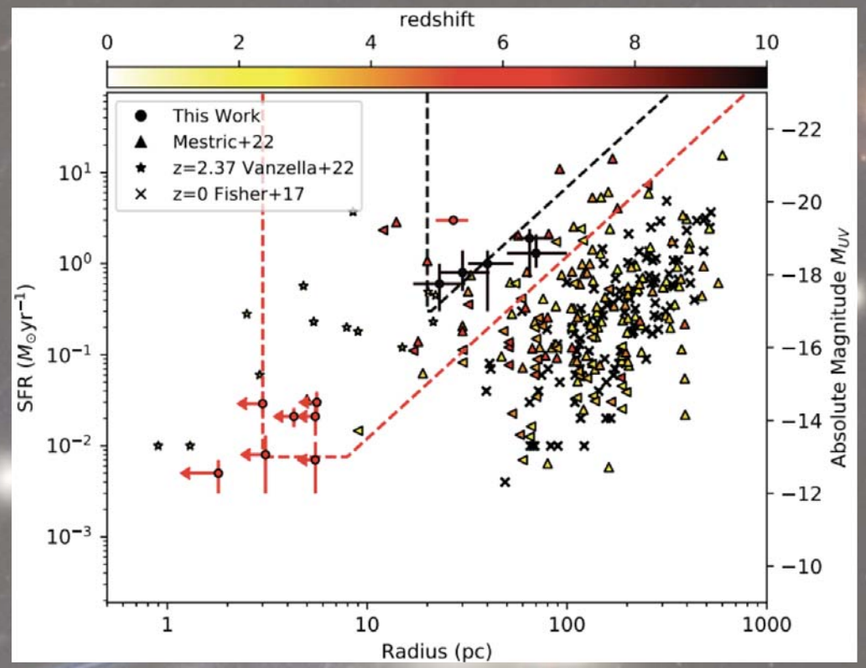
- ???

Welch+2022
- 5-10 sources
- z ~ 6 - 10 (photometry)
- various lens models
- forward modeling





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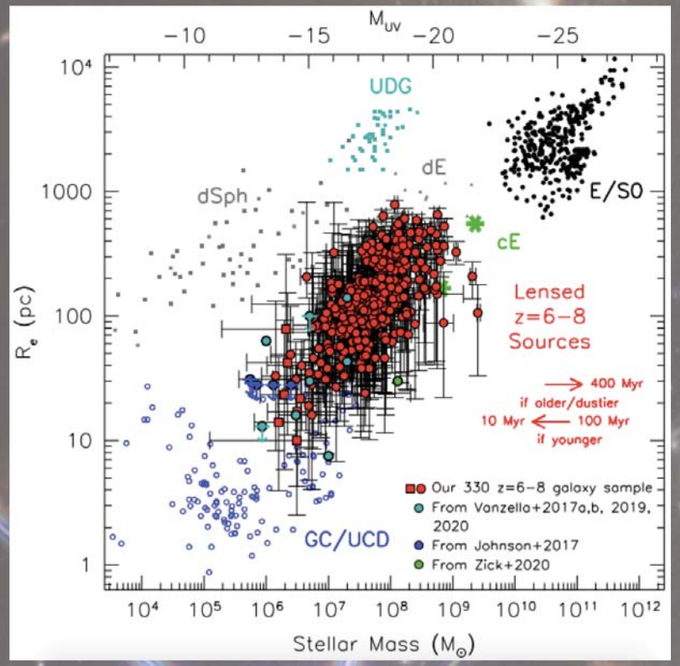
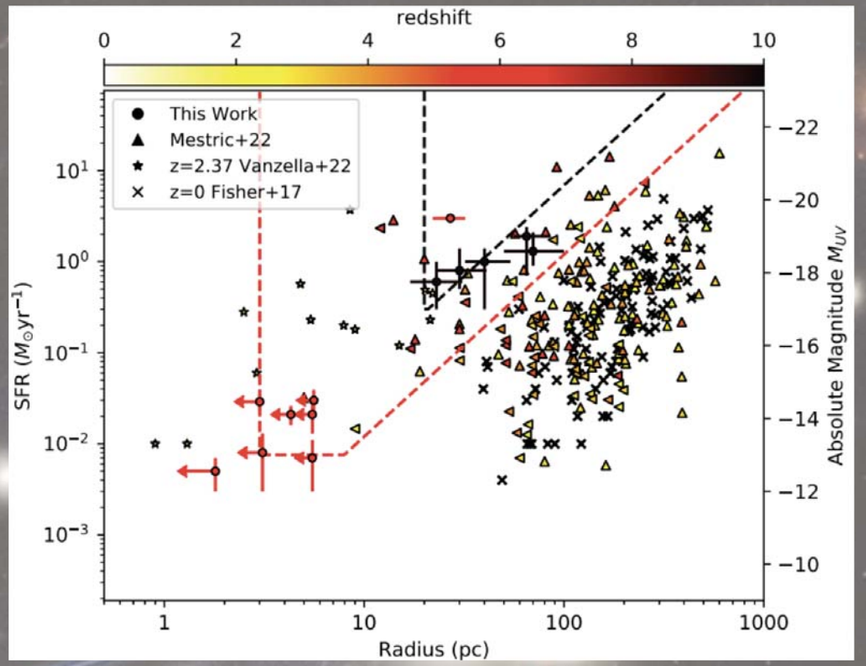
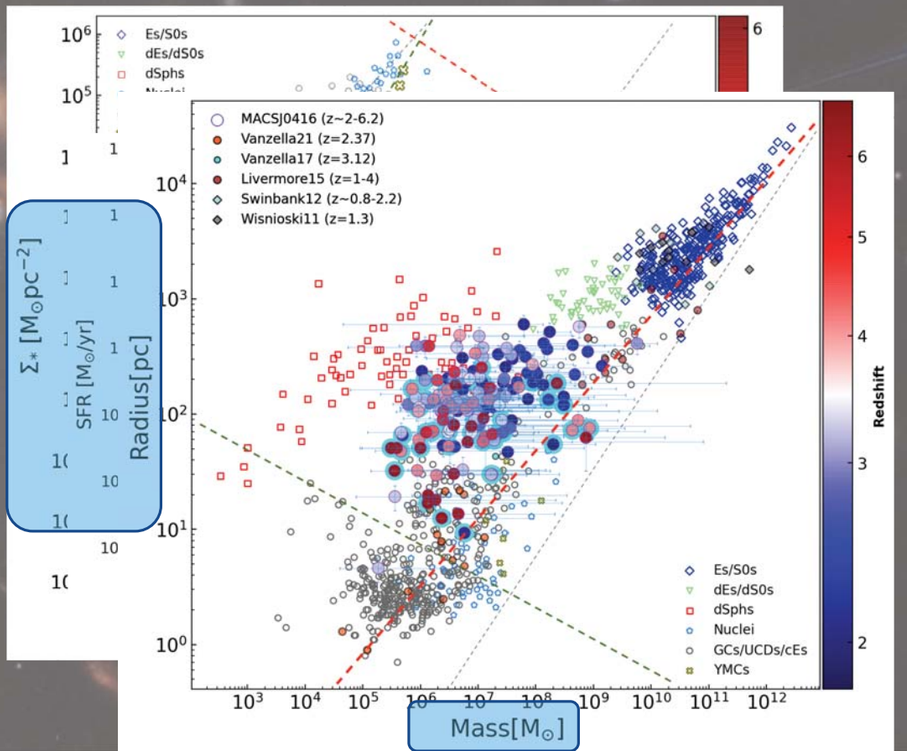
Vanzella+2022
Meštrić+2022
- 166 sources
- z ~ 2 - 6.14 (spectroscopy)
- Bergamini+2021
- Galfit







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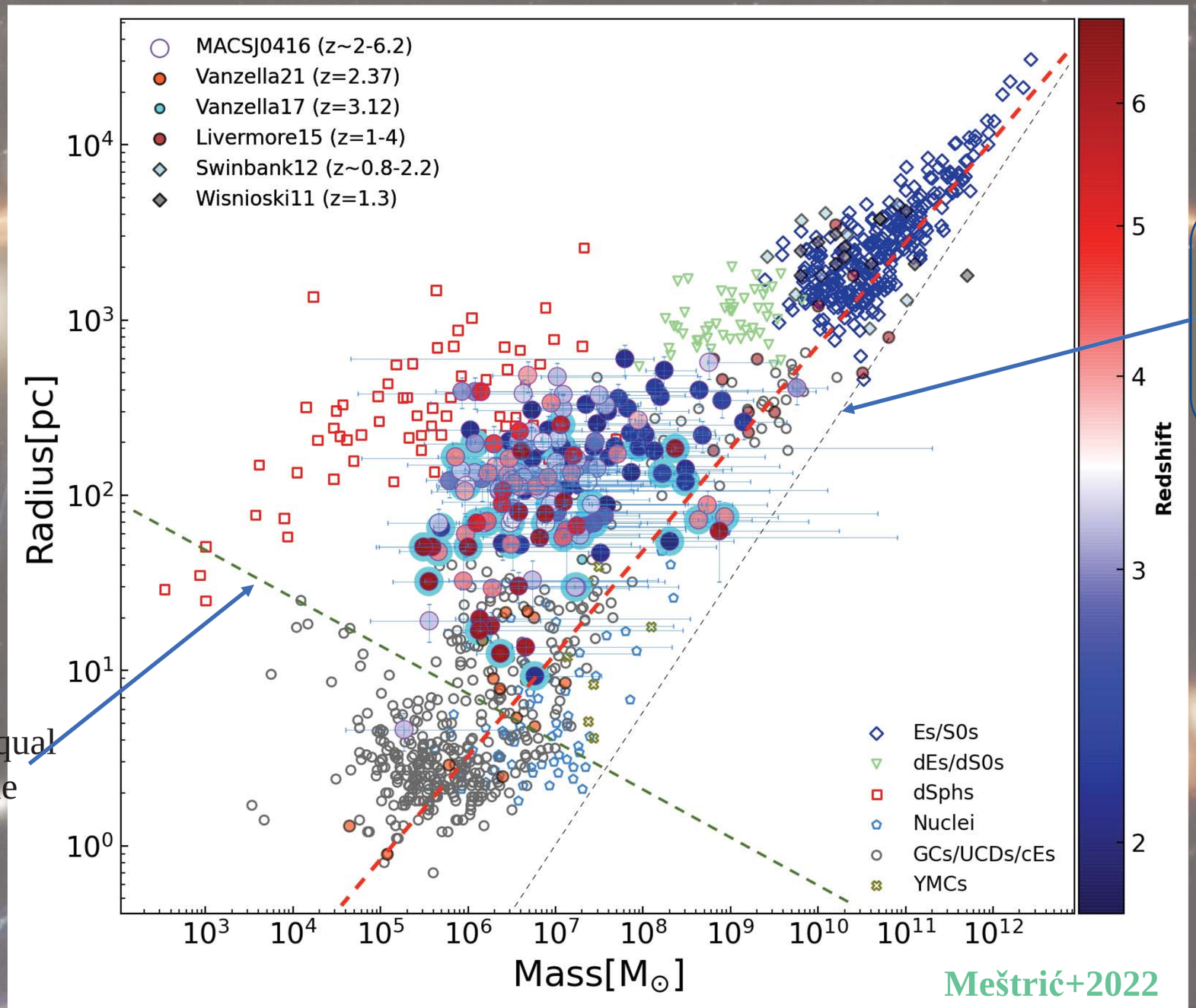
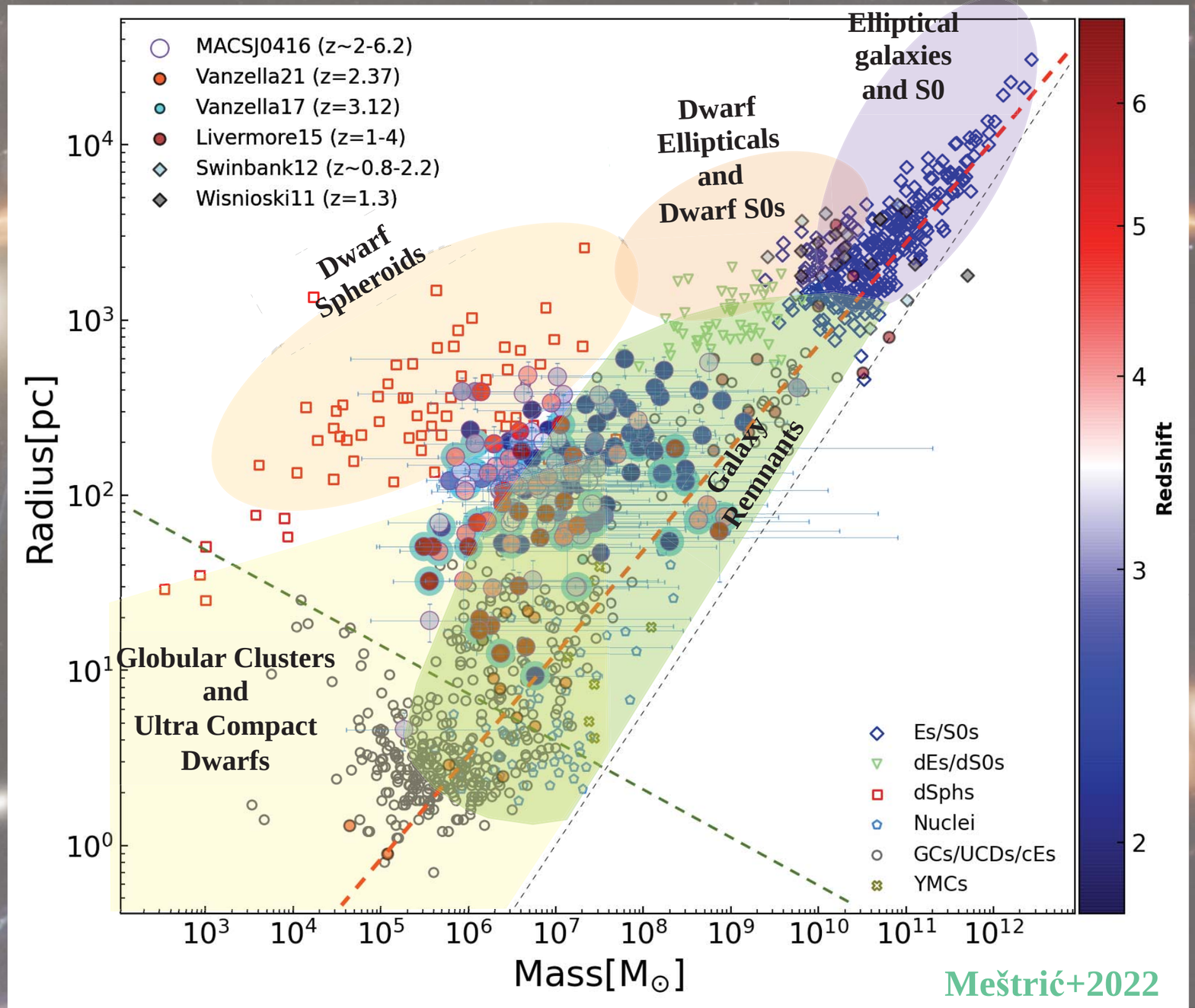


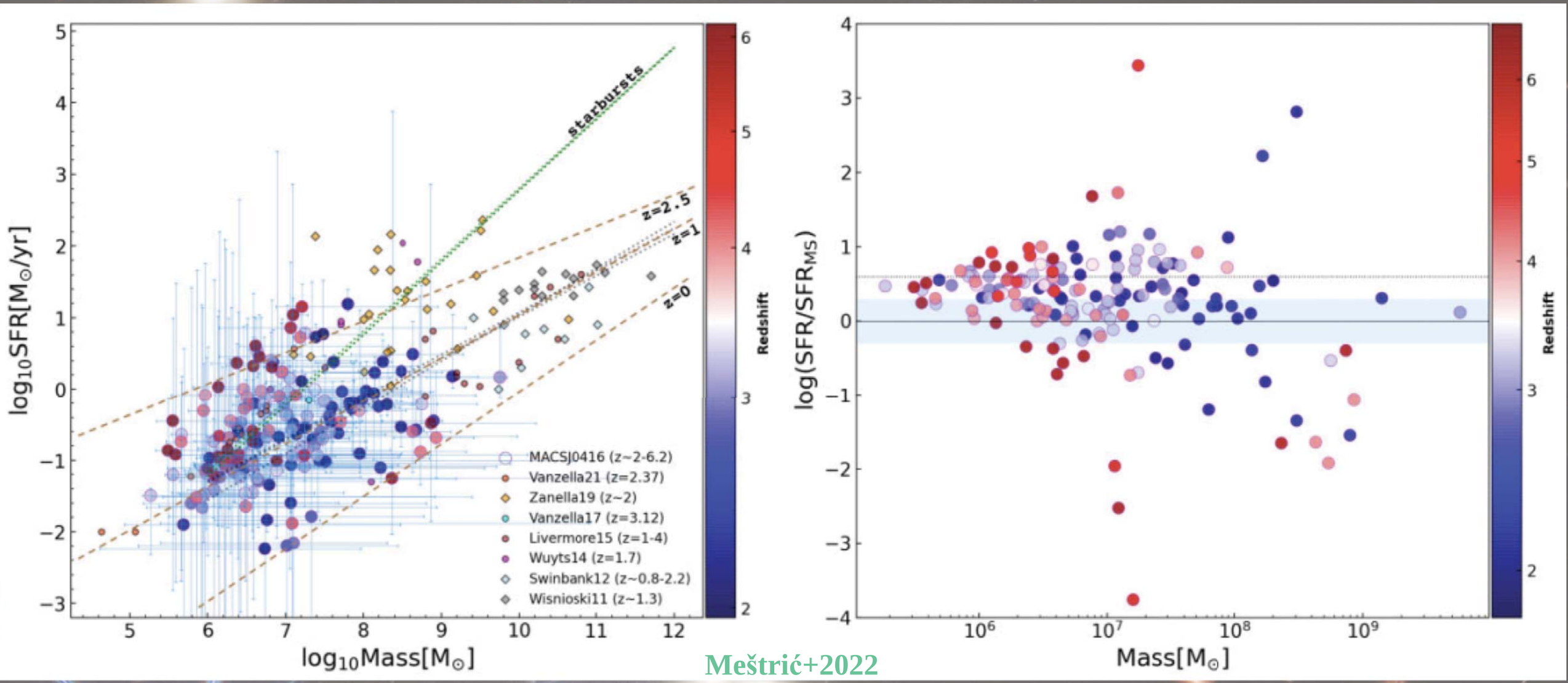
Zone of Avoidance
($R_{eff}(M) \geq c_1 M_\star^{4/5}$
Misgeld & Hilker 2011)
or
Zone of Exclusion
in k-space (**Burstein+1997**)

Relaxation time equal
to the Hubble time

Meštrić+2022

Clumps - *samples* -



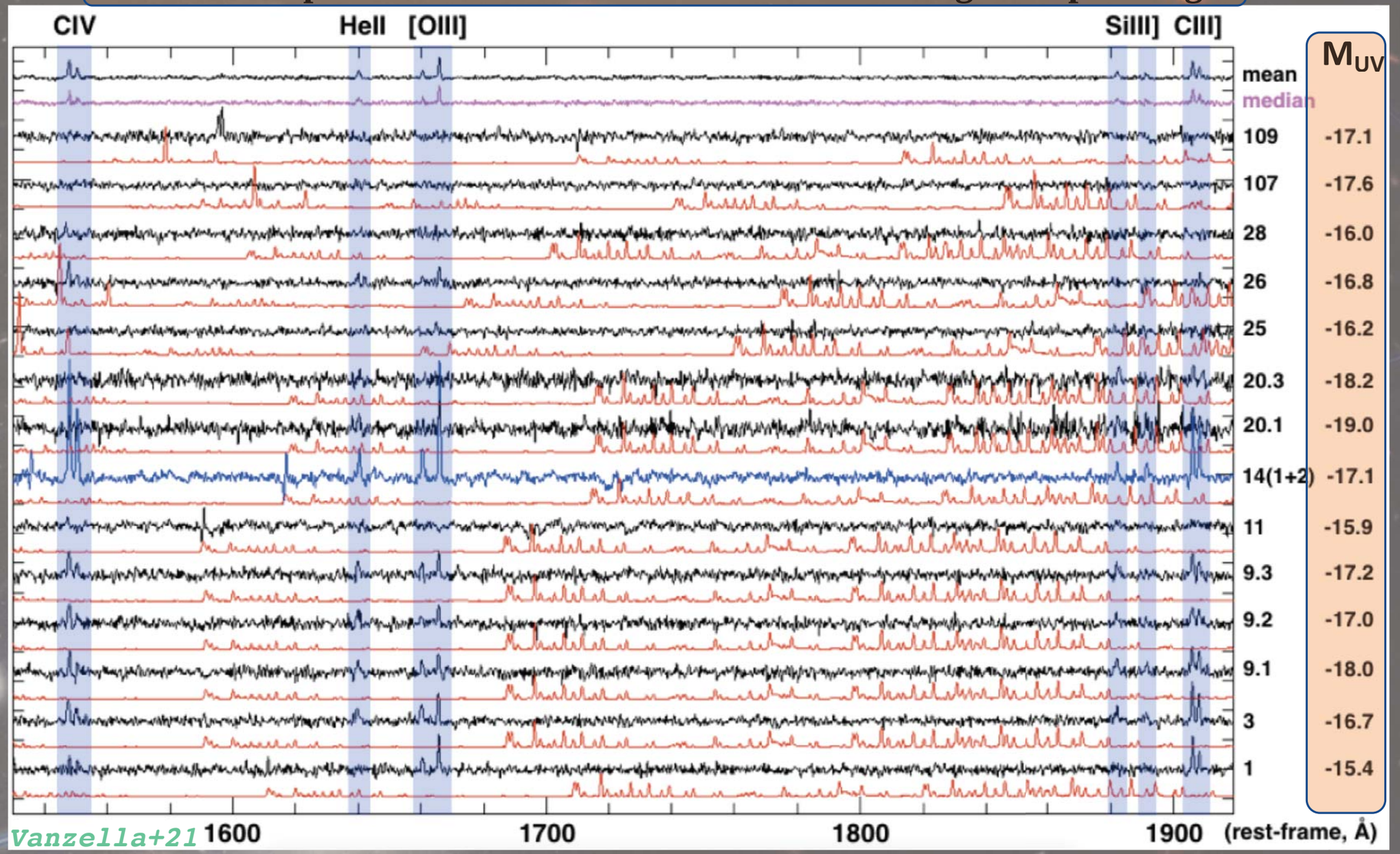


Meštrić+2022

Clumps - MUSE *spectroscopy* -

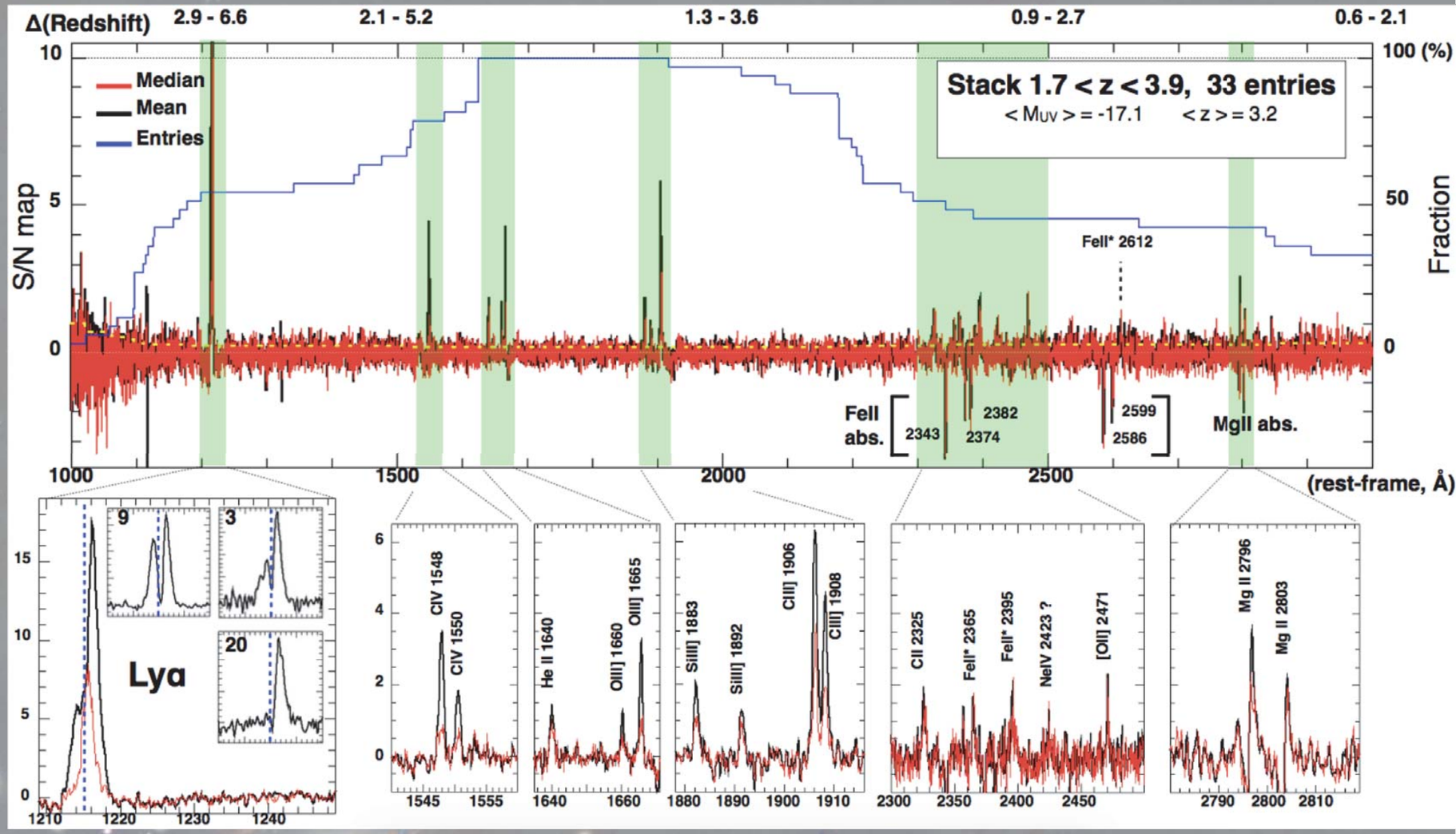
- Subsample of the clumps with Lyα in emission
- UV high-ionization lines CIV, HeII, [OIII], SiIII], CIII] observed.
- Presence of hot massive stars
- Indication for high ionizing photon production efficiency

2.9<z<3.4 exposure time from 17.1h – 51.3h … Lensing/multiple images



Clumps - MUSE *spectroscopy* -

- S/N stacked detection map (33 sources)
- Objects with Mases<10^8 $M_\odot$
- Similar stack presented in Rigby+2018 but with masses >10^9 $M_\odot$ → **showing fainter nebular emission lines**.
- At M_{UV} (-18 median) masses ($10^{8.4}$ $M_\odot$ median), bluer beta slope … → strong nebular emission lines observed in low-mass, high-z and faint LAEs (Feltre+2020).

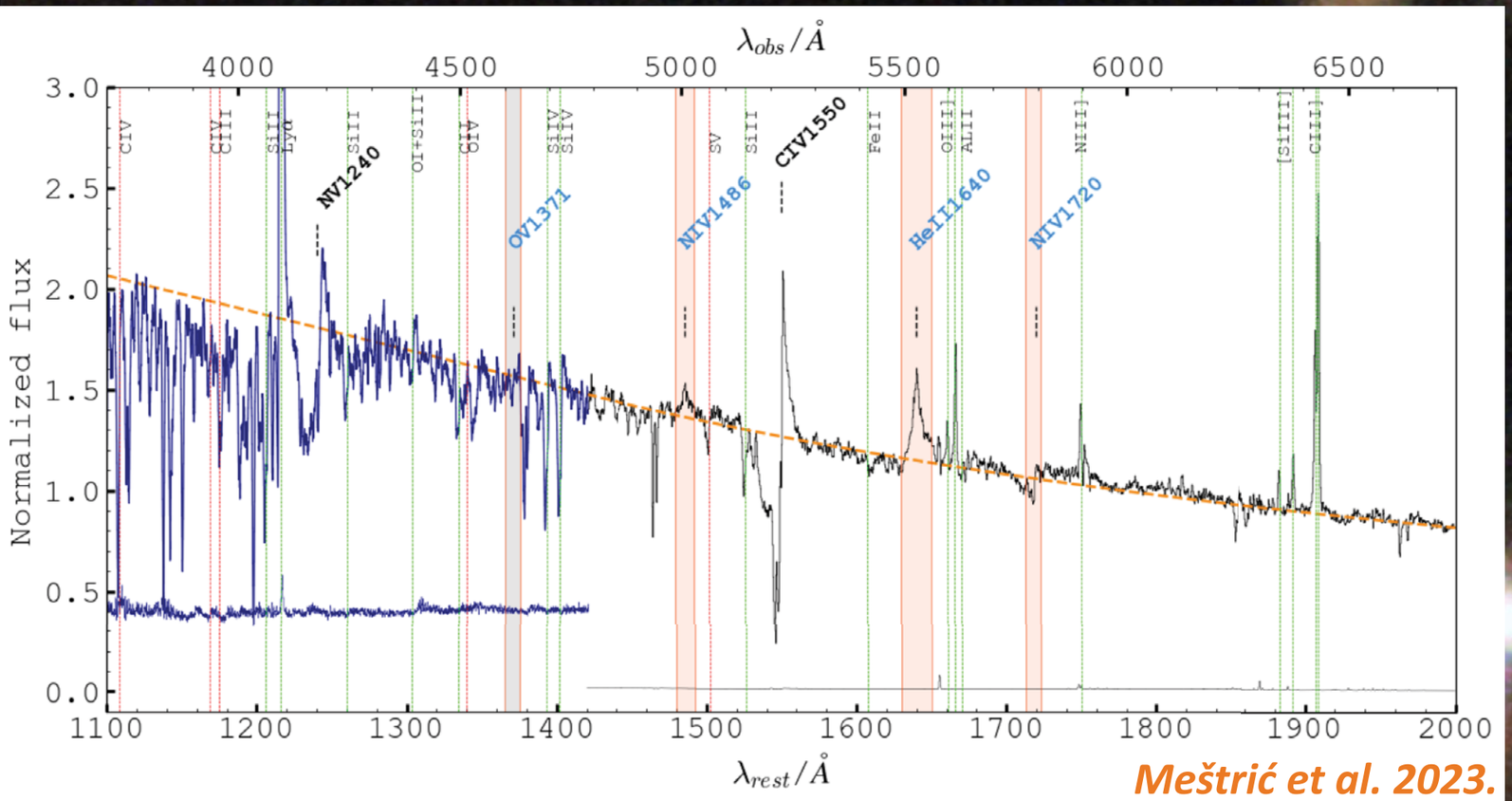


Vanzella+2021

ESA/Hubble, NASA, Rivera-Thorsen et al.
HST (F275W+F606W+F814W+F160W)

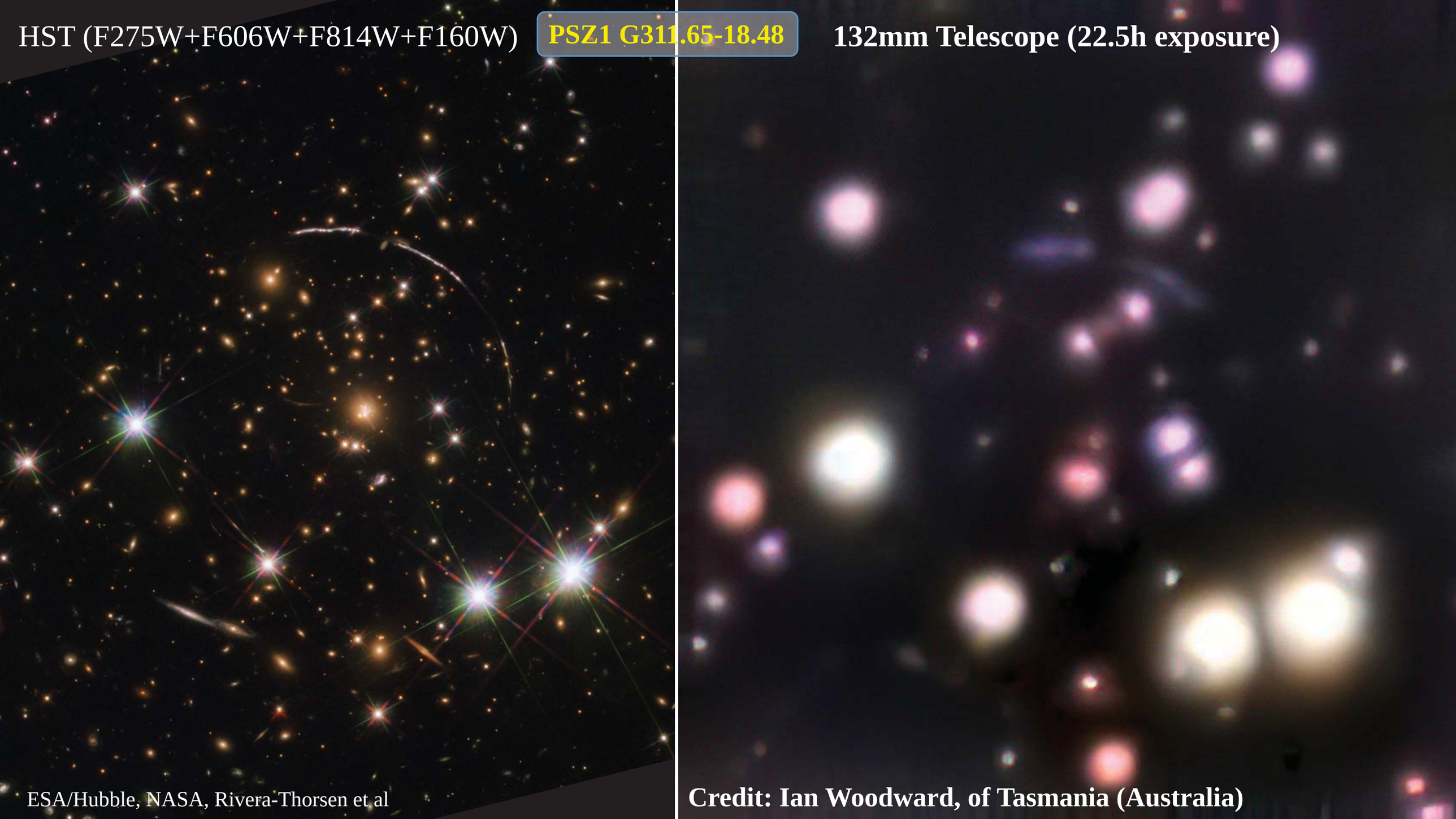
Sunburst galaxy at z=2.37

- **M_{VMS}= 150-200 Msol**
- **Existence of VMS (~370-400)**
- **~15% of LyC production (1% of total number of O-type stars)**
- **VMS segregation**
- **formed in the central parts of YMC**



Meštrić et al. 2023.

Godzilla (LBV star)
Choe et al. 2024.


HST (F275W+F606W+F814W+F160W)
PSZ1 G311.65-18.48
132mm Telescope (22.5h exposure)
ESA/Hubble, NASA, Rivera-Thorsen et al
Credit: Ian Woodward, of Tasmania (Australia)